Modeling the Effect of Climatic and Human Impacts on Margin Sedimentation

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LONG-TERM GOALS

Coordinate the EuroSTRATAFORM modeling effort. Model the hydrological routing of water and sediment into the Northern Adriatic and the Gulf of Lions. Determine the impact of changes in climate, the impact of humans, and fluctuations in sea level, on the transfer of sediment from land to sea. Determine the dispersal mechanisms of this terrestrial flux of sediment, including the impact of hyperpycnal discharge from rivers, and the coastal trapping of sediment of deltaic distributary channels.

OBJECTIVES

1A) Coordinate the EuroSTRATAFORM modeling efforts designed to formulate predictive and diagnostic models on how sedimentary processes contribute to the stratigraphic record.

2A) Determine the long-term and short-term climate changes, and the perturbations from human impacts, on the hydrological routing of water and sediment (e.g., floods, droughts) including the Po, selected rivers along the Apennines, and the Rhone River.

2B) Determine any connections between point-source and line-source sediment supply and sea level, and whether these connections control canyon morphology, failure frequency, and gravity flow dynamics. Determine if the formation and intensity of hyperpycnal flows generated at river mouths directly affects the position and formation of submarine canyons.

2C) Support the effort to understand how the dynamics of delta lobe switching frequency imparts a recognizable signature on margin architecture (e.g., through plume sedimentation).

2D) Support the effort to understand the dynamic response of a continental margin to large-amplitude sea-level changes, beginning with those of the last glacial cycle.

2E) Support the effort to develop coherent techniques for upscaling individual processes/events into long-term stratigraphic-architecture and seascape-evolution models.

APPROACH

1A) Through regular meetings and electronic communication, develop a NA-EU community of modelers who together develop a suite of numerical tools to model events affecting strata formation that are otherwise difficult to observe. The cumulative impact of these high-energy events can be

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predicted through numerical experiments, within the context of other relevant marine processes (e.g., earthquakes, tsunamis, storms, seasonal discharge). Have the EuroSTRATAFORM modeling group work closely with scientists collecting field observation, for insight and validation.

1B) Combine single-component models into a larger numerical framework, including the conversion of 2D-SedFlux into 3D-SedFlux. Encourage code sharing among participants of EuroSTRATAFORM.

2A) Locate and analyze the discharge records for key rivers in our Mediterranean study areas. Collect appropriate climate and geomorphic data for input to HydroTrend, and generate synthetic discharge data and sediment loads, across historical and geological periods. Make HydroTrend results (water and sediment discharge) available to other project participants. Predict flood probability distributions, and simulate conditions favorable to the development of hyperpycnal flows.

2B) Determine if the Apennines rivers are able to generate hyperpycnal flows. Model the interaction between long-shore currents and an evolving hyperpycnal or hypopycnal plume.

2C) Construct a numerical model to handle both autocyclic and allocyclic processes. Test the model against the switching frequencies of well-studied deltas. Add the delta-switching model to the 3D-SedFlux model and model the offshore sedimentation patterns given HydroTrend synthetic discharge data. Compare model results with field data from the Gulf of Lions and the Adriatic.

2D) Investigate the employment of two scaling techniques: (i) coherency-modified probabilistic frequency distributions (e.g. for river discharge), and (ii) application of statistical properties of Laplace-generated deposits within a compute-and-drift scheme. Scale between laboratory experiments and continental margin observations, employing SedFlux.

WORK COMPLETED

1A) Convened, hosted, participated, or organized workshops to ensure the success of EuroSTRATAFORM by: (i) integrating models across time and space, (ii) coordinating laboratory modeling efforts with numerical modeling efforts, (iii) coordinating proposed modeling and field efforts, and (iv) linking efforts with European EC projects: EURODELTA, PROMESS, and EU-EuroSTRATAFORM. Workshops presently in advanced planning stages include COMDELTA and the NA-EuroSTRATAFORM meetings in Aix, a 2 d session at AGU in San Francisco along with a separate 1 d modelers workshop, and a 1 day session at IGC in Florence.
1B) With support of Weltje (Delft) and Pratson (Duke) matched NA and EU modeling tasks through a series of questionnaire that were subsequently made available to the community through the web:
http://instaar.colorado.edu/deltaforce/projects/NA_euro_strataform/project_questionnaire.html
http://instaar.colorado.edu/deltaforce/projects/NA_euro_strataform/model_questionnaire.html

2A) *HydroTrend* — a model able to generate water discharge and sediment loads, across historical and geological periods — was rewritten to capture "live" climate data (using the web-based *DODS*: Distributed Oceanographic Data System) (Table 1). *HydroTrend* was verified in a "no-tuning" run of the model of the Lanyang River, Taiwan, by predicting the river mouth hydraulics (velocity, width and depth), average and daily sediment loads and water discharge, all within a few percentages of the observations.

Table 1. Comparison of observation and "no-tuning live capture" HydroTrend model predictions for the Lanyang River, northern Taiwan (a proxy river for the understudied Apennine rivers).

	OBSERVATIONS	HYDROTREND		OBSERVATIONS
		STATISTICAL SEQUENTIAL CLIMATE	**CLIMATE**	
Annual Q km^3/yr	**1.96±0.66***	**2.09±0.76**	**1.68±0.53**	**1.56±0.20***
Annual Q-peak m^3/s	**1245±638***	**1387±754**	**1257±447**	**1249±523***
Annual Qs kg/s	**232±528***	**235±170**	**240±2280**	**190±200***
Annual Cs kg/m^3	**1.6 ± 5.5#**	**0.43±2.1**	**0.40±2.0**	**0.7±2.4#**
Annual Cspk kg/m^3	**13.5 ± 20#**	**25.6±22**	**20.6±10**	**18.2±10.7#**
Years	**1951-1994**	**50 yrs**	**1978-1990**	**1978-1990**

Q is discharge, Qs is suspended load, Cs is suspended concentration. Observation values (mean ± standard deviation) based on annual rating curve determined from a few samples (#≈27 samples per year) distributed across the hydrograph.

2B) The Psi model was applied to global rivers and specifically to Italian rivers (Fig. 2). Sediment flux predictions are shown to be globally at the same level of accuracy as observations. Observational errors include estimates from too few samples; samples collected over too few years, bias in monitoring schedule, measurement techniques, and human impacts. Predicted errors include those related to input variables and local perturbations.

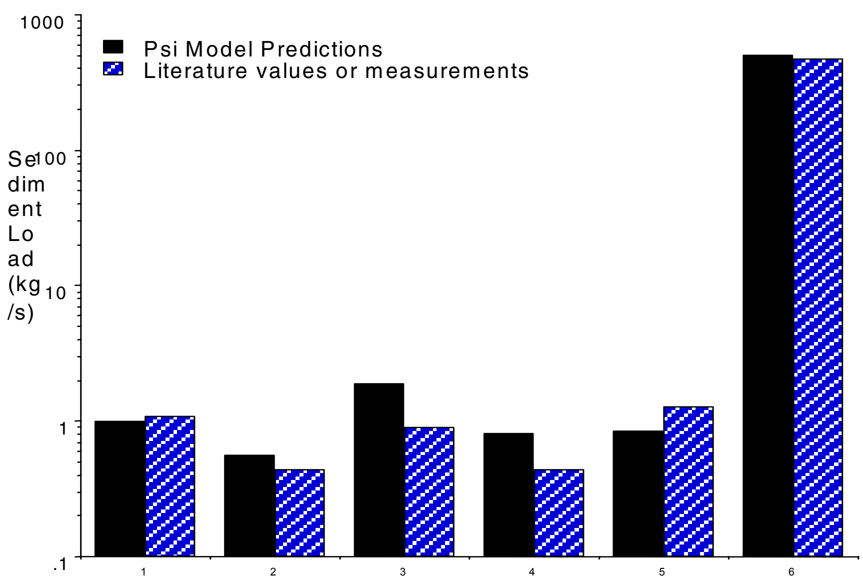

Figure 2. Comparison of Psi Model predictions for selected Apennine and Po rivers and literature values or measurements.

2C) *HydroTrend* was adjusted to incorporate the impact of reservoirs. The Po-river is strongly affected by 5 large reservoirs, as are the Apennine Rivers. The subroutine was tested successful against daily discharge data of the Po and the Pescara Rivers (the only two monitored rivers). The

subroutine incorporates trapping efficiency algorithms for both large (Brune model) and small (Brown model) reservoirs (Table 2).

2D) Predicted the hydraulics of water and sediment discharge through multiple river Po outlets (Fig. 3). The model accurately (to the level of the observational uncertainties) depicted the loads of the six-distributary channels.

Table 2. Five Apennine Rivers flowing under modern climatic conditions (annual precip. (m) is 0.62±0.22; and the annual temp. (°C) is 14.1 ± 1.4. Italic values are descriptors for rivers with reservoir situated on main trunk; non-italic values describe rivers under natural conditions.

River	TE	Δslope	Length	Relief	Area	Q_{avg}	Q_{peak}	Cs_{avg}	Qs_{avg}	Qb_{avg}	E(C)
(%)	(°)	(km)	(m)	(km^2)	(m^3/s)	(m^3/s)	(kg/m^3)	(MT/a)	(MT/a)	(-)	
Tronto		0.0056	86	2306	1211	8.6	1124	3.7	1.00	0.25	1.99
46						***350***	***2.0***	***0.50***	***0.15***	***1.90***	
Potenza		0.0023	89	1472	796	5.1	705	3.5	0.56	0.064	1.75
30						***218***	***2.4***	***0.39***	***0.049***	***1.69***	
Pescara		0.0021	154	2703	3302	29.2	2644	2.1	1.90	0.29	2.16
35						***993***	***1.4***	***1.30***	***0.20***	***2.10***	
Metauro		0.0022	91	1569	1438	10.7	1349	2.4	0.81	0.12	1.82
32						***414***	***1.6***	***0.55***	***0.086***	***1.76***	
Chienti		0.0040	99	1804	1255	8.9	1150	3.0	0.85	0.18	1.87
33						***362***	***2.0***	***0.56***	***0.13***	***1.81***	

TE = sediment trapping efficiency; Δslope = slope of delta plain used in bedload calculation; Length = length of main trunk; Relief = sea level to mountain top; Area = drainage basin; Q_{avg} = 100-y mean discharge; Q_{peak} = 100-y return-interval discharge; Cs_{avg} = 100-y mean discharge-weighted suspended sediment concentration; Qs_{avg} = 100-y mean suspended sediment load; Qb_{avg} = 100-y mean bedload; E(C) = rating coefficient.

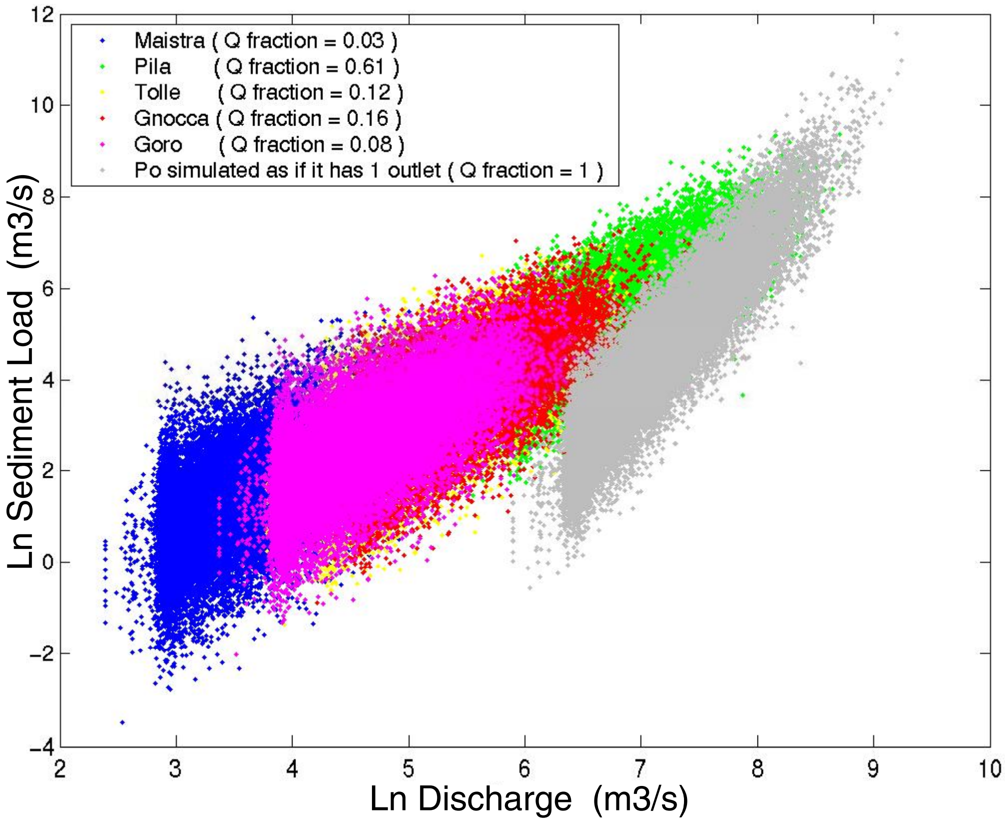

Figure 3. HydroTrend daily simulations of discharge for the Po at the last gauging stations before being split into distributary channels and then the simulations of discharge at the outlet of each of the five main distributary channels.

2E) The *HydroTrend* runs of the Apennine Rivers are being used by Jasim Imran (USC) as input to his hyperpycnal model; by Courtney Harris (UVA) for her live 2001 circulation model experiment; and by Lincoln Pratson (Duke) in his analysis of the changes in seafloor acoustics. The model is also available for EuroSTRATAFORMers http://instaar.colorado.edu/deltaforce/models/hydrotrend.html. Results are downloadable through http://instaar.colorado.edu/deltaforce/projects/euro_strataform.html for the Metauro, Chienti, Tronto, Pescara, and Potenza. Po River results will soon be available.
2F) A daily Late Glacial Maximum (LGM) simulation versus present climate using *HydroTrend* suggests little change in the suspended sediment load (16.1×10^6 t yr^{-1} today against 16.2×10^6 t yr^{-1} during LGM), given the cold climate of the LGM. Bedload is predicted to be twice as large at 8.2×10^5 t yr^{-1} during the LGM and implies coarser sediment flux during LGM compared to present.
2G) The Po, prior to the 12th Century AD, had no deltaic expression existed and the coast prograded at 4 m/a under the dominance of wave energy and rapid shifting of distributary channels. Since then and with increased anthropogenic soil erosion, progradation of a delta began. In 1604 the Venice Republic was threatened with the infilling of its protective Venice Lagoon. A diversionary channel fixed the modern river channel and distributary channels have become the chief locale for coastal progradation reaching rates of 60 to 130 m/a (Bondessan, 2000). SedFlux model is shown to duplicate these historical observations.
2H) SedFlux now includes the delta sequestering algorithm of Paola et al (1992) and the nearshore sediment transport model of Storms (2003).

RESULTS

The EuroSTRATAFORM modeling team has advanced rapidly a field of models to characterize the littoral zone. Models are capable of ingesting remotely sensed environmental data and provide predictions on the flux of sediment to the coast, within the coastal zone, and across continental margins. Many of the models are robust, having been tested in a number of environments. However model improvements continue, taking into account new processes of less importance in other modeled environments. The modeling of the Adriatic system has highlighted the impact of both large and small reservoirs. The later affects the number of hyperpycnal events that are generated by the rivers of the Apennine. The Po system now reflects the impact of large hydroelectric dams on both sediment and water discharge. The Po also reflects the impact of distributary channels in mitigating the dispersal of hypopycnal (surface) plumes by distributing the energy across a wider coastal zone. By combining modeling efforts from Europe and NA, models such as SedFlux have grown to incorporate new modules able to handle a wider range of sedimentary processes, such as the development of lagoons.

IMPACT/APPLICATIONS

New numerical tools predict the general nature of seafloor morphology and the developing sediment stratigraphy, and allow for realistic characterization of the littoral zone. Tools ingest environmental data they provide seafloor information of continental margins at the global level. By being able to model river systems under natural conditions and under anthropogenic influence, the INSTAAR models provide a powerful tools to investigate both paleo and engineered conditions.

TRANSITIONS

ExxonMobil is using versions of *HydroTrend* and *SedFlux* in their industrial applications. The International Geosphere Biosphere Program uses the models to examine the global water system through its core projects (GWSP and LOICZ).

RELATED PROJECTS

ONR Geoclutter: http://instaar.colorado.edu/deltaforce/projects/geo_clutter.html
ONR Seabed Uncertainty: http://instaar.colorado.edu/deltaforce/projects/dri.html
NSF Community Sediment Model: http://instaar.colorado.edu/deltaforce/workshop/csdms.html.
NSF MARGINS: http://instaar.colorado.edu/deltaforce/projects/margins.html

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